4-6 K Ball Aerospace Long Life Space Cryocoolers

Dave Glaister and Willy Gully

(303) 939-5842
dglaister@ball.com

TPF Science, Technology and Design Expo
October 14-16, 2003

Ball Cryocooler Strengths

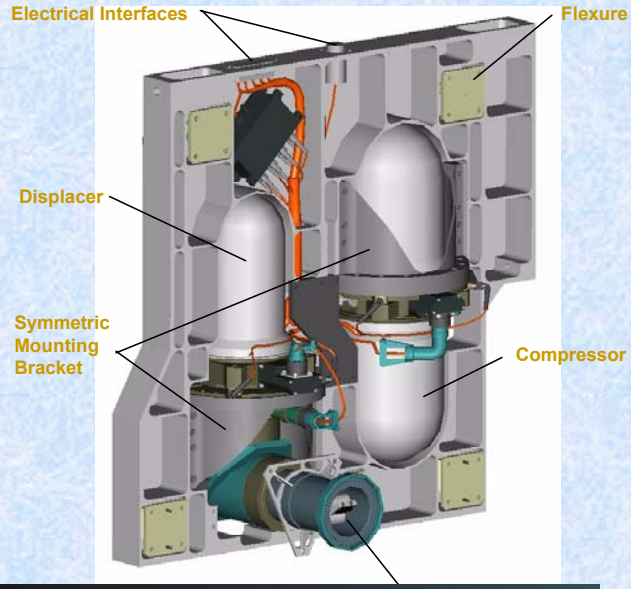
- **Cryogenic Systems Expertise – For over 40 years, Ball has done and continues to do more space cryogenic work than another organization in the world**
- **Low Temperature Specialization – Over a decade of <20 K space cryocoolers culminating in the 4-10 K cryocooler**
- **Multi-Stage Expertise – Over a decade of multi-stage flight cooler that are optimum for dual loads and low temperatures**
- **Build-to-Print Systems – Build-to-Print SB160 and SB235E Coolers and E200 and E300 Electronics**
- **Strong Emphasis on System Integration – Unique integration features of the Ball cryocoolers minimize integration risk, thus, significantly reducing the overall program risk**

Ball Cryocooler Expertise Based on Specialization in Low-Temp Cryogenics

- **Ball Aerospace has experience with more than:**
  - **40 years on cryogenic spaceflight instruments**
  - **18 years on cryocoolers**
  - **11 years on multi-stage Stirling coolers**
  - **150 cryogenic space flights**

Ball Cryogenic Systems Engineering

- Historically, Cryogenic Systems are Relatively Difficult to Develop
  - Space cryogenics is very personnel dependent
  - Industry expertise base is declining
- Ball Specializes in Cryogenic Systems
  - Built space cryogenic systems for nearly 50 years
  - Over 150 cryogenic system flights
  - Over 2000 man-years of cryogenic expertise
  - More than 80 people currently supporting cryogenic programs
- Ball Builds and Integrates Cooling Sources
  - Mechanical cryocoolers
  - Dewars (cryostats)
  - Cryoradiators
- Ball Designs and Builds Cryogenic Instruments



Ball Cryocoolers Cover Wide Range of Applications with Multiple Technologies

- Multiple Long Life Cooler Product Lines
  - Each optimum for different application envelopes
  - Each based on proven long life designs
- Stirling Coolers
  - Very compact and power efficient
  - In build for over a decade
- Joule-Thomson Coolers
  - Inherent load leveling capability
  - Optimum for stable temperature over distributed cooling interface
  - In build for over a decade
- Hybrid Coolers
  - Combines advantages of Stirlings and J-Ts
  - Optimum for low temp (<10 K) applications
- Optical Cooler
  - Very long life (no moving parts)
  - Very compact, light, with tight integration
  - Zero vibration, zero EMI
  - Low-cost manufacture

Flight Qualified 1, 2, and 3-Stage Ball Stirling Coolers with Significant Life Testing

- Long Life, Multi-Stage Stirlings since 1989
- Flight Qualified 1, 2, and 3-Stage Coolers
- Flight Qualified Drive Electronics
- 1-Stage Cooler (SB160 or HIRDLS)
  - Optimum at 60 K and above
  - 2 Flight Units delivered for NASA Aura
  - ~5,000 hrs. on HIRDLS Coolers
  - ~27,000 hrs. on SA160
- Next Gen 2-Stage Cooler (SB235)
  - Build-to-print, qualified cooler
  - Optimum for FPA & Optics cooling
  - Mass and power efficient, high capacity, producible cooler
- 3-Stage Cooler (SB335)
  - Optimum for <30 K
  - ~17,000 hrs. on qualified SB335
  - SB315 precooler for Ball ACTDP 6 K Cooler
- Heritage 2-Stage Cooler (SB230)
  - ~20,000 hrs. on SB230 (11,000 hrs. on displacer)

1-Stage HIRDLS

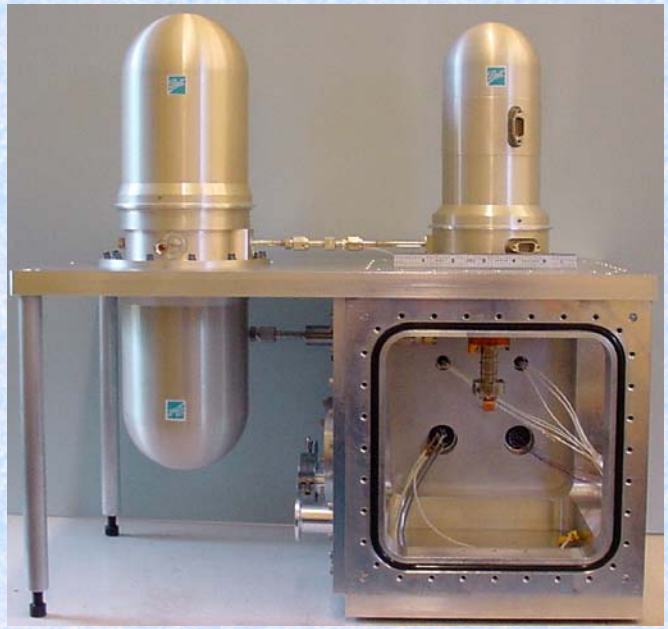
2-Stage 30 K

3-Stage 35/60 K

2-Stage SB235

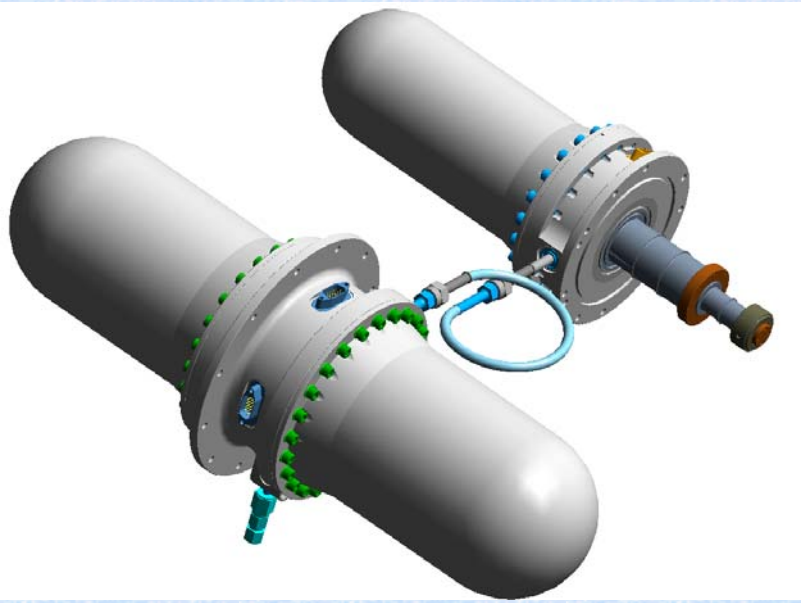
SB235 Cryocooler

- SB235 Stirling Cryocooler
  - Ball's 3rd Generation Multi-stage 35 K Cooler
  - Designed for producibility with increased efficiency & capacity
  - Met SBIRS Low Coude' (SDR) Track rqmts.
  - Fight qualified unit entering life test
- Performance improvements over SOA
  - 2-3 X cooler capacity
  - ~40% increased power efficiency
  - ~50% increased mass and volume efficiency
- Producibility/Cost improvements
  - 30% reduced parts count
  - 75% reduced match-machining
  - Reduced complexity & simplified assembly
- Performance
  - 0.5 W @ 40 K & 3.5 W @ 110 K for 90 W motor
  - 99% reliability at 10 years
  - 10.5 kg mass



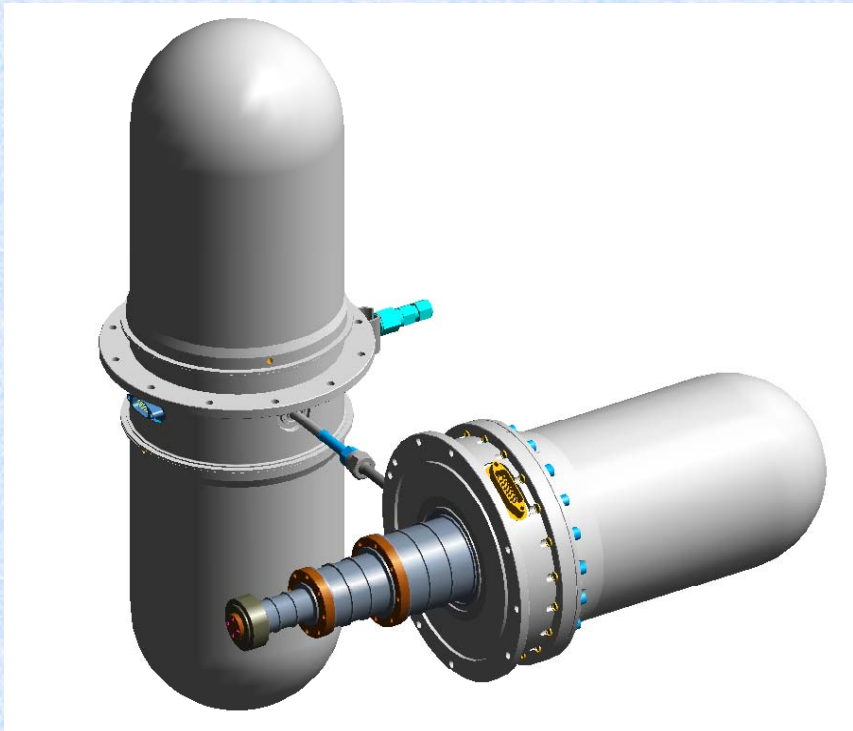
Build-To-Print Ball SB235E Cryocooler System

- Higher capacity model derivative of qualified SB235
  - Qualified SB235 unit entering life test
  - Baselined IPDR cryocooler for the Raytheon SBIRS Low Track Sensor
  - Baselined for NASA/JPL Advanced Cryocooler Technology Development Program (ACTDP)
- Build-To-Print Cooler
- Performance
  - Higher mid-stage capacity than SB235
  - 1.2 W @ 40 K & 12.0 W @ 110 K for 171 W motor
  - 3.2 W @ 56K & 14.6 W @ 120K for 205 W motor
  - 2.6 W @ 56K & 11.7 W @ 120K for 176 W motor
  - 99% reliability at 10 years
  - 12.9 kg mass



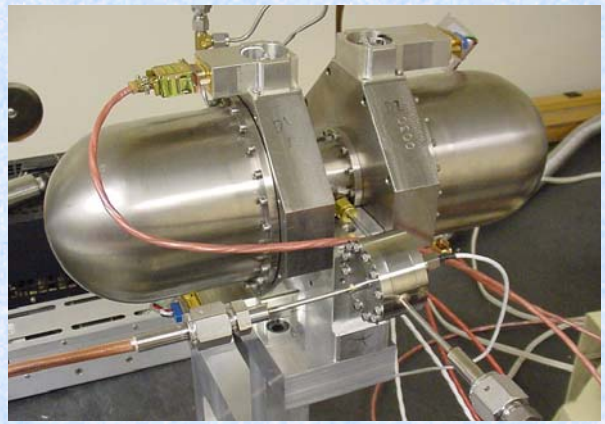
SB315 Cryocooler

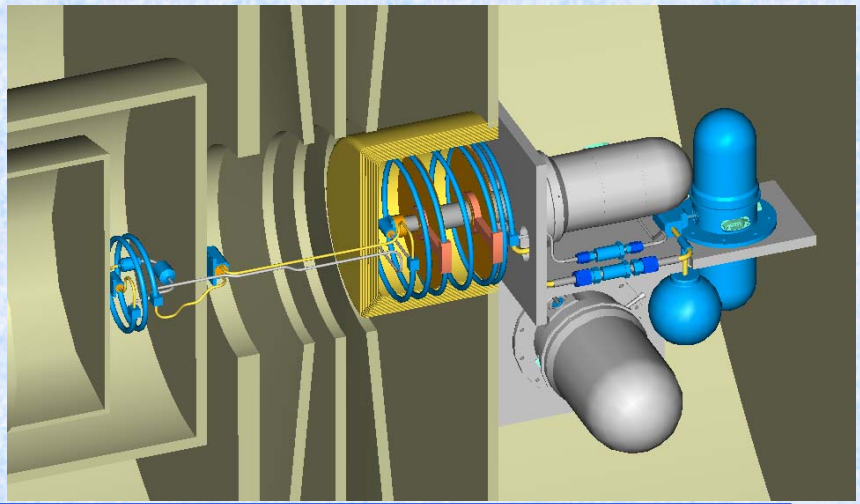
- 3-Stage Cooler for cooling below 15 K
  - Highly leveraged of SB235 and SB335 coolers
    - High capacity from SB235
    - 3-Stage cold tip from SB335
  - ACTDP Precooler for 4-6 K J-T cooler
  - Engineering Model in build on NASA/JPL's ACTDP program.
- Performance
  - Higher mid-stage capacity than SB235
  - 0.3 W @ 15 K & 1.0 W @ 40 K & 2.0 W at 180 K for 180 W motor
  - 99% reliability at 10 years



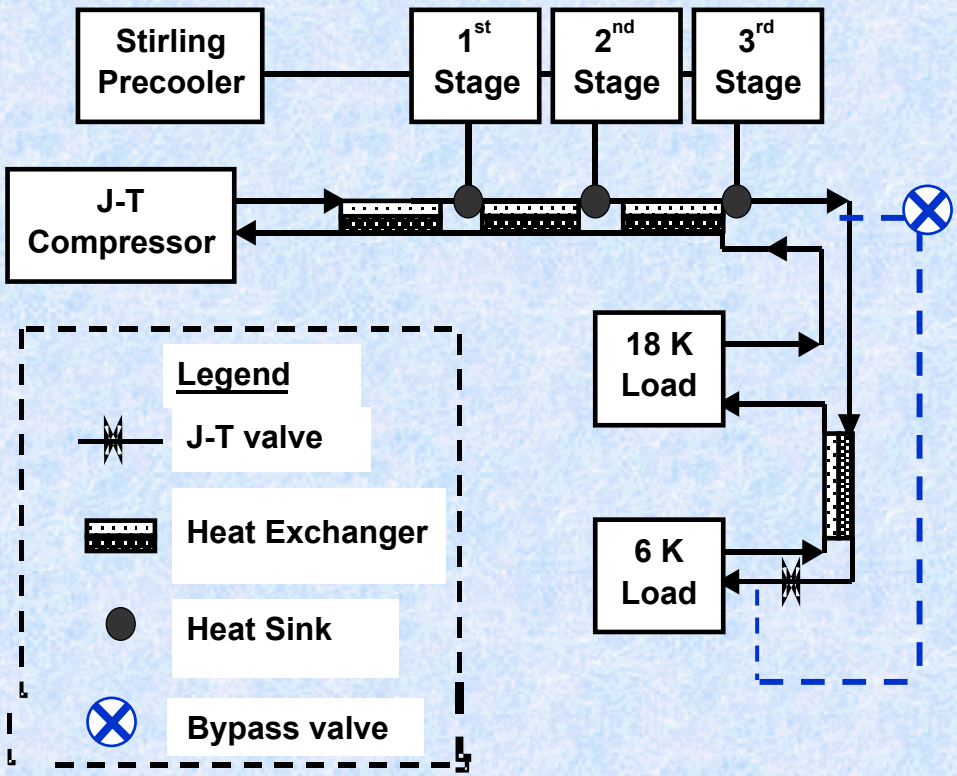
Ball 4-10 K (ACTDP) Cryocooler

- ACTDP (Advanced Cryocooler Technology Development Program)
  - NASA/JPL 6 K cooler development for JWST, TPF, and Con-X programs
  - 3 years culminating in Engineering Model
  - DoD application to 10 K VLWIR systems
- Cooler design is at Post-PDR level
  - Design detailed down to piece-part level
  - Leveraged off previous Ball Stirling and J-T hardware
- Performance
  - 30 mW @ 6 K (or 20 mW @ 4 K) & 150 mW @ 18 K for 125 W motor
  - On-orbit 2X load change capability
  - 5X change by swapping J-T valve
  - 30 kg
  - >20 m remote heat transport



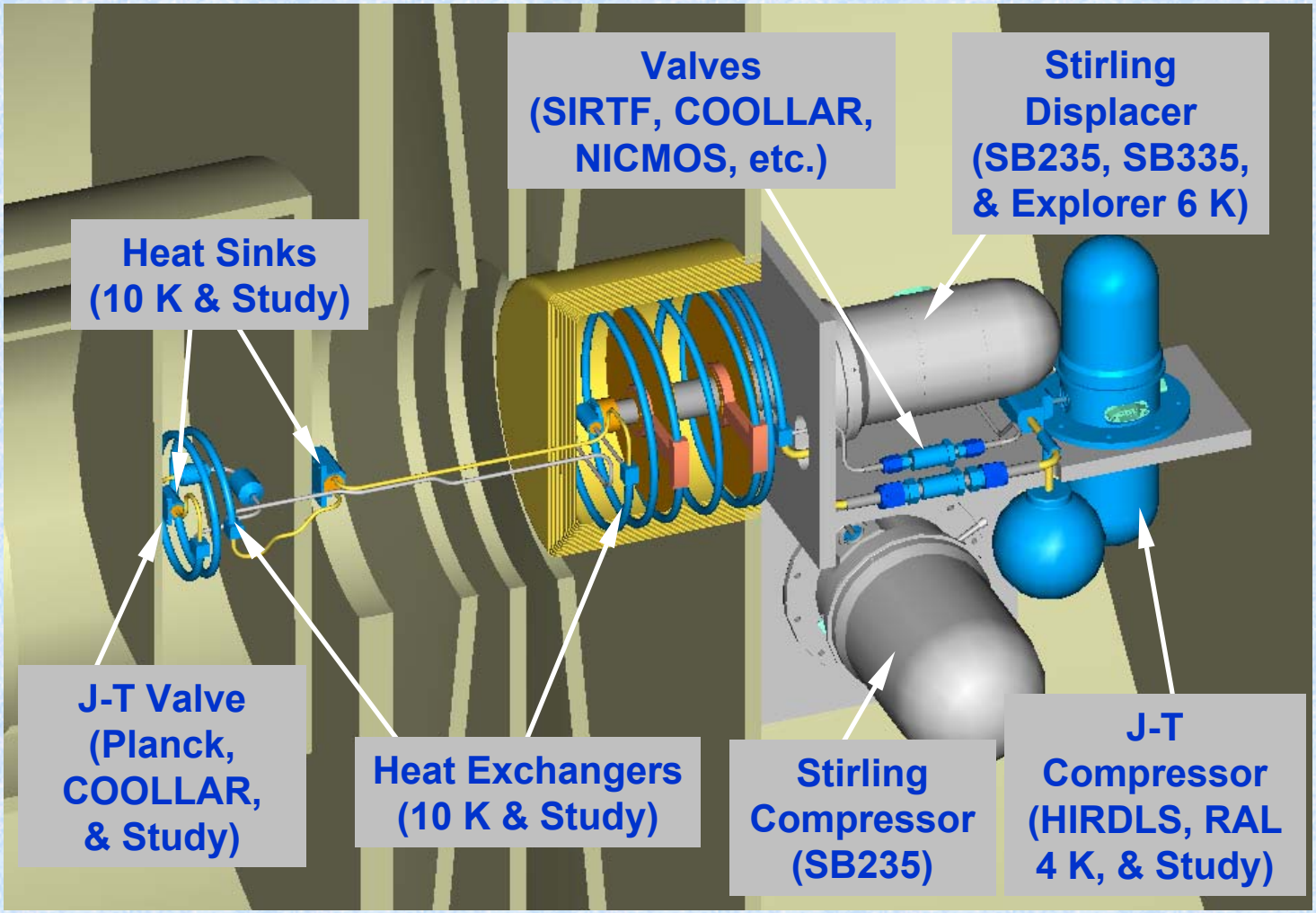


Operational Fundamentals



- Optimum combination of two cooling cycles
  - Proven Stirling efficiency to cool from ambient to 15 K
  - J-T recuperative efficiency to cool below 15 K
- Two methods of cooling at the two loads
  - J-T directly cools 6 K
  - J-T provides transport/ circulation of Stirling 18 K cooling after 6 K
- Bypass added to expedite cooldown

All Cooler Components Proven in Test on Study Phase and Previous Programs



ACTDP Cryocooler Highly Leveraged Off Previous Development

Ball Aerospace Cryocooler Development → **Enables**

NASA 30 K
2-Stage Stirling
in Life Test

AFRL 35/60 K
3-Stage Stirling
in Life Test

NASA 6 K Explorer
3-Stage Stirling
EM Tested

HIRDLS Flight
1-Stage Stirling
Qualified and
Delivered

Ball SB235 and E300
2-Stage Stirling & Electronics
SB235 Qual'd, Life Test 1/02
SB235E & E300 in Flight Build

RAL 4 K Cooler
Reed Valve
in Life Test

DOD COOLLAR
2-Stage J-T
Flew in Space, in Life Test

AFRL 10 K
Hybrid Stirling/J-T
EM in Assembly
at Redstone

JPL Planck
Sorption J-T

Precooler
- **Stirling Displacer**
- **Stirling Compressor**
- **Electronics**
- **J-T Compressor**
- **Filters, Disconnects**
- **Heat Exchangers**
- **J-T Valve**

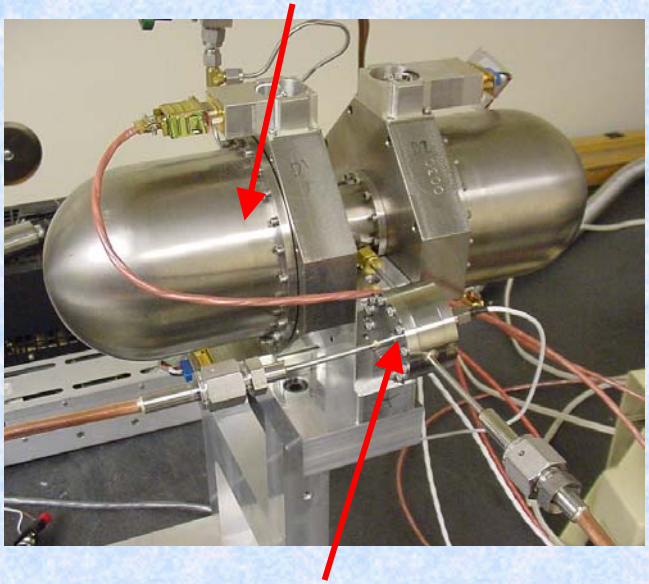
Circulator and Cold Stage

ACTDP Cryocooler Hybrid Stirling/J-T

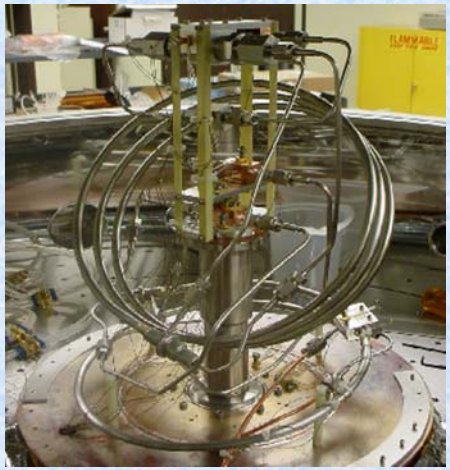
All Technology Components Verified in Test

- Culminated in successful 4 and 6 K system tests (35 mW @ 6 K, 21 @ 5 K, 12 @ 4 K, 0 @ 3.4 K)

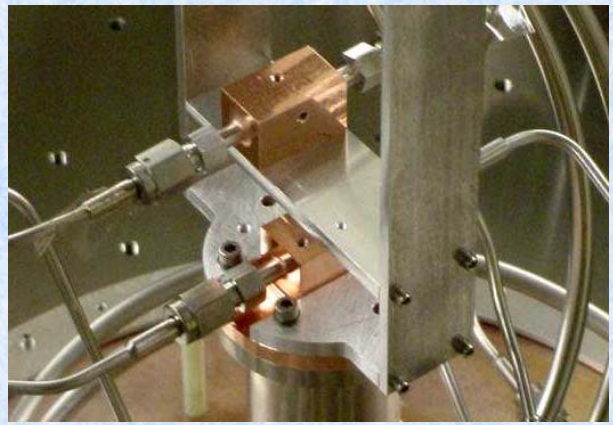
Long Life, Linear Compressor



Heat Exchangers



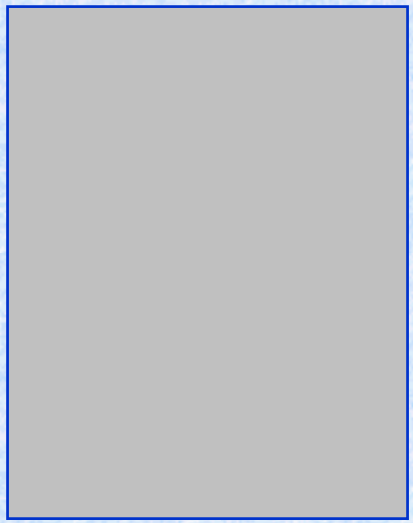
Heat Sinks



J-T Valves

ACTDP Cooler Design Optimized for Critical System Integration

- Remote heat transport (no moving cold head parts)
  - No moving cold head parts can be deployed and located >20 m from compressor suite
- No cryogenic radiator required or needed
  - Equally applicable to Earth and non-Earth orbit missions
  - No stray light or thermal back load on instrument
- Mature thermal/mechanical integration system
  - Including structural supports/thermal insulation
  - Conceptual integration into JWST, Con-X, and other program designs
- No 0-g concerns or 1-g testing limitations
  - Single phase, gaseous working fluid
- Independent control of 6 and 18 K heat loads
  - Real-time, on-orbit capability to adjust ±2x to actual conditions



Ball Aerospace Cooler Integrated into Con-X XMS